PRACTICAL AND THEORETICAL ASSESSMENTS OF SUGARCANE YIELD POTENTIAL IN NATAL

BY J. GLOVER
S.A.S.A. Experiment Station Mount Edgecombe.

Abstract

In order to estimate the capabilities of our present varieties the actual yield of millable cane from a crop of variety N55/805, grown on a coastal red sand soil and managed to the best of our present knowledge, has been compared with the theoretical maximum possible yield calculated on the basis of the most efficient use of our sunlight under the most perfect conditions of growth.

The result shows that this variety is capable of attaining at least 70% of the maximum possible yield under management as we understand it at present and, by implication, that other good local varieties can do likewise.

Introduction

How good are our commercial varieties? It is known that so far as sucrose content % dry matter at harvest is concerned they are capable of ranking among the highest in the world, yet do they produce enough stalks to give maximum possible yields when grown under the very best conditions that we can supply at present or in the future?

To answer this we must obtain some reasonable estimate of maximum possible yield under the average sunshine regime we can expect locally. Then, having got such an estimate we can compare it with actual yields from field trials conducted under the best conditions we can provide at present. The first sets a target of yield at which we should aim, even though we suspect it is impossible of attainment with present methods of management. The second will set the minimum levels of yield to be equalled or surpassed by new varieties and define our present efficiency of production.

Maximum Possible Yield

When a crop is perfectly supplied with water and nutriments the amount of plant material it makes by photosynthesis is a function of the amount of usable light energy falling on its leaves, the efficiency with which the leaf uses that energy and the level of carbon dioxide (CO_2) in the air around the leaves. As the level of carbon dioxide around the leaves does not normally vary very widely about a fairly constant value, it is reasonable to assume that production of photosynthate by the leaves depends only on the usable energy in sunlight and its efficiency of use by the leaf.

Photosynthesis at 100% Efficiency

If the leaf employs all the usable radiant energy falling on it at 100% efficiency then the maximum possible production of photosynthate in the Mount Edgecombe area can be estimated knowing:

(a) that although the surface of a crop is not perfectly horizontal the total amount of radiation received by the crop is closely estimated by the amount of radiation measured on a horizontal surface (Baker & Musgrave [1])

(b) that the total energy supply month by month throughout the life of a crop is the average total energy on a horizontal surface at Mount Edgecombe over the last six years.

(c) that the usable energy for photosynthesis is 8% of the total incoming energy (Monteith [6]).

(d) that the heat of combustion of 1gm of carbohydrate (CH_2O) = 4 200 calories.

(e) that the crop has been planted on the 1st October and is harvested one year later and that the ground cover by leaves follows the pattern shown in Table 1, which is in outline that of an irrigated crop grown under good conditions.

TABLE 1

The average radiation regime at Mount Edgecombe, the percentage ground cover and the estimated gross carbohydrate production month by month.

Month	Av. radiation ly. mth^{-1}	Average Ground cover %	Gross (CH_2O) production t.ha^{-1}.mth^{-1}
Oct.	12927	16	3.94
Nov.	13500	49	12.60
Dec.	15562	73	21.64
Jan.	15252	100	29.05
Feb.	13300	100	25.33
March	13609	100	25.92
April	10530	100	20.05
May	9393	100	17.89
June	8370	100	15.94
July	9114	100	17.36
Aug.	10943	100	20.84
Sept.	11220	100	21.37
	Total for the year		231.93

The data in Table 1 shows that by assuming 100% efficiency of use of incoming energy by the leaves of the crop the gross production of carbohydrate would amount to some 230 t. dry matter ha^{-1} by the end of a year after planting.

Photosynthesis at a known leaf efficiency

In practice, leaves cannot operate at 100% efficiency. As light intensity increases the efficiency of use decreases, so much so that in

most plants other than tropical grasses a saturation point is reached. With tropical grasses however light saturation is not reached at normal levels of irradiation and for sugarcane the relationship between light intensity and maximum rate of photosynthesis is of the form shown in Figure 1 (Irvine[5] Hesketh and Moss[3] and others). Although the curve showns in fig. 1 has been calculated for a maximum production of CH_2O) equivalent to 66mg CO_2 dm^{-2} hr^{-1} at 1.5 ly min^{-1} such as is common for the CP varieties reported by Irvine[4], the choice of scale is unimportant within wide limits. The curve is used only to obtain a measure of the average efficiency of light use. If it is integrated between zero and 1.65 ly min^{-1}, that is over almost all the normal range of irradiation intensity encountered in practice it can be shown that the average maximum efficiency of light use in this range, by a sugarcane leaf, is about 70%. This may now be used to correct the gross assimilation at 100% efficiency. The highest estimate of **gross** practical assimilation will now be 230 x 0.7 or 161 $t.ha^{-1}$ yr^{-1} of dry (CH_2O).

Net Assimilation

Net assimilation which is the source of all the plant growth that can be directly measured is the difference between gross assimilation and respiration. We must therefore derive some estimate of the respiration of a crop which is capable of producing 161 $t.ha^{-1}$ yr^{-1} gross assimilation.

Results from the respiration laboratory of this Station provide information about the dark respiration of the stalks and leaves of whole, rooted plants which may be used in the calculations. A detailed description of these respiration measurements will be described elsewhere. A brief summary of the relevant results is as follows:—

(a) the dark respiration rates of rooted, living stalks (Rs), expressed as mg (CH_2O) min^{-1} kg^{-1} dry wt may be estimated by the equation $Rs = 0.2495\ T - 3.046$.

where T is the average night temperature in °C.

(b) leaves respire at rates some three times more actively than stalks when the respiration rates are expressed on the same standardized dry weight basis

(c) 1 ha. leaves weigh about 1.354 t. ha^{-1} dry matter, (average of Nco 376 and N55/805 measurements).

If the dry matter distribution between leaves and stalks is known month by month throughout the year the respiration losses from these parts of the top may be summed over that period, while suitable allowance can be made for root respiration.

In making such calculations the daytime respiration of the crop must be taken into account. It cannot be measured directly because most of the liberated CO_2 is quickly re-assimilated. However, it may be assumed that it proceeds in the same manner as dark respiration although at higher temperature levels. As a result an estimate of whole plant respiration may be calculated by using monthly mean temperatures (max + min/2).

Although there is one record of the distribution of the dry matter of the various parts of the crop during the growth of an irrigated crop on a shallow soil in this region, the early growth of this crop was not markedly different from that of a non-irrigated crop. To simulate even faster growth, the existing data, in combination with other data relating to growth in height of stalks in irrigated deep soils, have been used to derive a faster growth pattern, that is different stages of growth are assumed to be attained some two months earlier than we attained in practice on the shallow soil. The approximate changes in moisture content of the stalk with increasing age and "ripening" during winter are also known so that it is possible to derive a pattern of the changes in dry weight of stalks throughout the year. Leaf area

TABLE 2

Ground cover, leaf area index, area and weight of leaves, stalk dry weight and stalk moisture content as well as the calculated 24 hour respiration of leaves and stalks separately.

	Ground cover %	Average L.A.I.	Area of leaves ha^{-1}	Weight of leaves $kg.ha^{-1}$	Stalk dry wt. $kg.ha^{-1}$	Stalk moisture content %	Day + Night Respiration kg. (CH_2O)	
							Leaves	Stalks
Oct.	16	1.5	0.24	325	—	—	89	—
Nov.	49	2.0	0.98	1326	—	—	394	—
Dec.	73	3.0	2.19	2965	1800	80	1040	211
Jan.	100	5.0	5.0	6769	14200	80	2529	1768
Feb.	100	4.5	4.5	6092	22550	78	2092	2582
March	100	4.5	4.5	6092	27890	78	2178	3325
April	100	4.0	4.0	5415	31510	77	1558	3022
May	100	4.0	4.0	5415	35160	76	1225	2651
June	100	3.5	3.5	4739	38500	75	736	1994
July	100	3.5	3.5	4739	40950	74	711	2047
Aug.	100	3.5	3.5	4739	45080	72	838	2655
Sept.	100	3.5	3.5	4739	47270	71	1006	3347
						Total respiration	14396	23602

will remain reasonably constant throughout a month for as new leaves are unfolded old ones die. The leaf area index and percentage ground cover will herefore provide a measure of the active leaf area in any month and (c) above enables its expression as dry weight of leaves.

Root respiration cannot be calculated directly. As our root laboratory records show the roots of our varieties are most active and extend very rapdily early in the life of a spring planted crop. As the crop ages the main roots suberize or lose most of their extra-stelar tissue and much of the root activity at this stage is confined to growing tips and the much fewer new roots and branches. This activity may be visualized in terms of top growth if one thinks of the active root tips as "leaves" and the old brown conducting strand of main root behind them as "stalks". Thus root respiration might be calculated as some fraction of top respiration. This fraction may be taken as 10% of the respiration of the tops since in Hawaii (Van Dillewijn[7]) it was found that roots made up some 12.7% of the dry weight of the total crop at one year old. As is shown later, even the use of half or twice this value makes no practical difference to the final calculations.

The result of the considerations concerning leaves and stalks is shown in Table 2. The final crop of millable stalks is assumed to be 163 t. ha^{-1} yr^{-1} at 71% moisture content.

Table 2 shows that the total respiration of the tops of a crop which would provide 163 t. ha^{-1} yr^{-1} of millable stalks is 38,0 tons of (CH_2O). The root respiration would be 3.8 tons on the assumption mentioned above. So the total loss of carbohydrate by respiration would be some 42 tons.

This value for respiration loss may be used in a preliminary estimate of net assimilation. Thus the latter will be 161-42 or 119 tons of dry matter. How might this be distributed? Data from Java and Hawaii (Van Dillewijn[7]) for 12 month crops show that stalks as a percentage of the total crop including trash, range from some 40 to 49% of the whole, while for a dryland crop of NCo 376 of the same age in Natal the stalks were also some 49% of the whole dry matter production of the tops (Gosnell-[2]). The value is obviously a function of the genetic characteristics of the variety. Some varieties will have more leaves in proportion to stalks and roots than others. However, if it is assumed that the stalks make up 50% of the total crop it cannot seriously be in error and it may be a slight overestimate in favour of a higher estimate of maximum potential yield.

The preliminary estimate of the dry matter of stalks will therefore be 50% of 119 tons or 59.5 tons. At 71% moisture this represents a harvestable crop of some 205 tons of fresh stalks.

This trial estimate is obviously out of balance because the respiration of a crop which produced 163 tons of fresh stalks has been used to estimate what turns out to be a much higher yield. The correct balance point must lie between these figures.

A heavier crop of stalks can be produced by the same area of leaves, so leaf respiration need not be altered. Only the respiration of the stalks need be adjusted. A few trials show that the respiration of a crop corresponding to some 198 tons ha^{-1} yr^{-1} of fresh stalks satisfies all conditions. This then is the estimate of **maximum** possible production of fresh stalks at 71% moisture in our average radiation regime.

Comparison with Actual Yields

How does this estimate of maximum possible production of fresh stalks compare with the best actual yields in carefully measured field experiments?

In the maximum production trials conducted by the Agronomy Department of this Station on a coastal Red Sand soil near the Station 142 t. ha^{-1} yr^{-1} was achieved by a plant crop of N55/805 and the succeeding 12 month ratoon crops gave similar or slightly higher yields. It would appear, therefore, that under what is at present thought to be very good management on a sandy soil this variety achieves at least some 70% of the estimated maximum possible production of net assimilate. Other good varieties would undoubtedly produce a similar result.

The Stability of the Estimate of Maximum Practical Yield.

The estimate of stalk yield of some 200 t. ha^{-1} yr^{-1} under perfect conditions is moderately stable because production is so heavily dominated by the amount of gross photosynthate. As calculated above the respiratory loss is only 29% of gross photosynthate production after correction for leaf inefficiency. Even if the true value lay between 26 and 32% there would be no significant change in the estimate. For example if the true respiration was 26% the estimate would be 205 t. ha^{-1} yr^{-1} of fresh stalks, while if it was 32% it would be 190 t. ha^{-1} yr^{-1} of fresh stalks. Since the difference represents some 10 tons in respiratory loss it is obvious that the assumption of either 5, 10, 15 or 20% of top respiration as root respiration is unimportant.

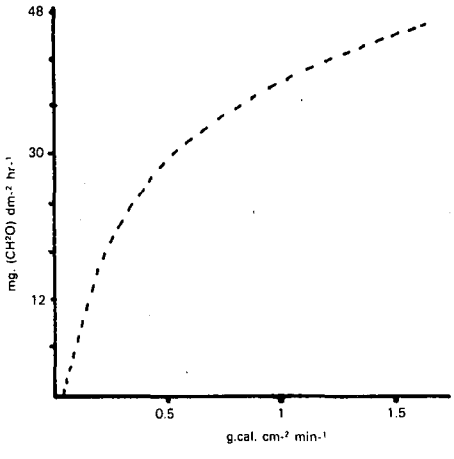

Fig. 1. The relationship between the rates of photosynthesis of newly unfolded mature sugarcane leaves and the level of irradiation.

REFERENCES

1. **Baker D.N. and Musgrave R.B.** 1964. Photosynthesis under field conditions V. Crop Sci. 4 : 127-136.
2. **Gosnell, J.M.** 1967. The Growth of sugarcane Ph.D. thesis Dept. Crop Science Univ. Natal, Pietermaritzburg. R.S.A.
3. **Hesketh, J.D. and Moss, D.N.** 1963. Variation in the response of photosynthesis to light. Crop Sci. 3 : 107-110.
4. **Irvine, J.E.** 1967. Photosynthesis in sugarcane varieties under field conditions. Crop. Sci. 7, 297-300.
5. **Irvine, J.E.** 1971. Photosynthesis and stomatal behaviour in Sugarcane leaves as affected by light intensity and low air flow rates. Physiol, Plant. 24, 436-440.
6. **Monteith, J.L.** 1966. The photosynthesis and transpiration of crops. Expt. Agric. 2, 1-14.
7. **Van Dillewijn, C.** 1952. Botany of Sugarcane. The Chronica Botanica Co. Waltham, Mass., U.S.A. 371p.